Risk Assessment to Support the Wastewater Treatment Exemptions (Headworks Exemptions) Proposed Rule

U.S. Environmental Protection Agency
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Table of Contents

Table of Contents (continued)

List of Figures

Page

List of Tables

1.0 Introduction and Overview

1.1 Background

On May 19, 1980, the U.S. Environmental Protection Agency (EPA) listed several wastes as hazardous under RCRA. This list is found in 40 CFR 261 Subpart D, and continues to be amended and updated. After the listings were promulgated, several industry groups became concerned that due to the mixture and derived from rules, large volumes of wastewaters (and their resulting treatment sludges) would become listed hazardous wastes. On November 17, 1981, after investigating the data provided by industry, EPA promulgated a rule (46 FR 56582 - 56589) giving several exemptions to wastewater mixtures from the mixture rule under 40 CFR 261.3(a)(2)(iv)(A) - (E). These exemptions are commonly called the "headworks rule." The headworks exemption allows wastes containing specific chemicals to be treated as nonhazardous wastes if the concentration of these chemicals in the waste at the headworks of the wastewater treatment train is less than 1 ppm for carcinogens or 25 ppm for noncarcinogens.

In the original listing, EPA listed several chemicals or classes of chemicals as hazardous wastes when used as solvents and subsequently spent (spent solvents codes F001 through F005). On February 25, 1986, EPA listed as hazardous wastes four other solvents in the F002 and F005 categories (51 FR 6537 - 6542): 1,1,2-trichloroethane, benzene, 2-nitropropane, and 2-ethoxyethanol (or ethylene glycol monoethyl ether). At that time, EPA did not determine whether or not to add these solvents to the headworks rule exemptions.

In August 1999, EPA received a request from the American Chemistry Council (ACC, formerly the Chemical Manufacturers Association) to add the above four solvents (1,1,2-trichloroethane, benzene, 2-nitropropane, and 2-ethoxyethanol) listed in 1986 to the headworks exemption. EPA decided to evaluate the requested additions of the four chemicals to the exemption list. EPA considered each solvent's risks individually in the analyses presented below.

1.2 Overview of Methodology

The purpose of this effort was to support the determination whether to expand the headworks exemptions to include 4 solvent wastes. We estimated what the risks may be from expanding the exemption to include four solvents: 1,1,2-trichloroethane, benzene, 2-nitropropane, and 2-ethoxyethanol (or ethylene glycol monoethyl ether). EPA evaluated the management of these spent solvents as non-hazardous: (1) for the direct treatment of the spent solvent wastewaters; and (2) for the resulting sludges during management.

EPA designed a two-phased analysis to evaluate the potential risks from the proposed expansions to the headworks exemption. In Phase I, EPA conducted a screening analysis to evaluate the risks by comparing the current regulatory levels in the solvents headworks exemption for other solvents (i.e., 1 ppm and 25 ppm for carcinogens and non-carcinogens, respectively) with protective waste concentration limits for these four solvents based on exposure to: (1) ground water contaminated by surface impoundment leachate; and (2) inhalation of chemicals volatilized from an aerated tank. For those solvents that did not pass the Phase I screen, EPA conducted a Phase II analysis using a more detailed assessment of the risks from three of the four spent solvents (2-nitropropane was excluded; see Section 2.2.2 for rationale) by evaluating the release, fate, and transport of the spent solvents managed in different types of non-hazardous waste treatment units. This human health risk assessment evaluated both the direct groundwater pathway and indirect exposure pathways for spent solvents released from either the wastewaters or the resulting treatment sludges.

1.2.1 Phase I Screening

The purpose of the Phase I efforts was to determine if, under conservatively protective exposure scenarios and assumptions, the current exemption levels of one and 25 ppm would be protective. EPA screened the air and groundwater risks from management of wastewaters for benzene, 2-ethoxyethanol, 2-nitropropane, and 1,1,2-trichloroethane using existing protective levels for wastes managed in non-hazardous management units.

For the air pathway, EPA used previously generated results for aerated treatment tanks from the Air Characteristic Study (U.S. EPA, 1999). The results selected from this study for screening analysis were calculated at a risk level of 1E-6, hazard quotient (HQ) equal to 0.25, and a receptor distance of 150 meters from the source.

For the groundwater pathway, EPA used the leachate concentration threshold values (LCTV) obtained from the Industrial Waste Evaluation Model (IWEM) (U.S. EPA, 2002). (The LCTV is the acceptable leachate concentration at the bottom of waste management unit that will result in a downgradient well concentration corresponding to the health based number (HBN) for a chemical.) EPA used the IWEM modeling scenario corresponding to an unlined surface impoundment, a risk level of 10^{-6}, HQ equal to 1, and a distance of 150 meter for the receptor well. EPA did not consider risks from sludge management or indirect pathways in Phase I.

1.2.2 Phase II Assessment

> **<u>Direct Pathways</u>:** An individual is directly exposed to the contaminated medium, such as air or groundwater, into which the chemical was released.
>
> **<u>Indirect Pathways</u>:** An individual is indirectly exposed when a chemical that is released into one medium (for example, air), is subsequently transported to other media, such as water, soil, or food, to which the individual comes in contact.

The purpose of Phase II efforts was to perform a more detailed assessment of the groundwater risks from the management of wastewaters that did not pass the Phase I groundwater pathway screen. EPA assessed risks for management of the wastewaters in several types of waste treatment units; sludges from the wastewater treatment units were evaluated in landfills and land application units. The sludge assessment considered potential groundwater risks from landfills and aboveground (indirect) pathways for land application units. The indirect pathway analysis was a screening analysis. We used a risk level of 1E-05 and HQ of one for decision analyses in Phase II.

EPA conducted the Phase II assessment for spent solvents managed in nonaerated surface impoundment and tank units (see Figure 1-1) and for an aerated biological wastewater treatment train (Figure1-2). The aerated biological treatment train consisted of a primary clarifier, an activated sludge unit, and a secondary clarifier. Only the activated sludge unit is aerated. EPA evaluated the units shown in Figures 1-1 and 1-2 to determine both central-tendency and high-end exposures to a receptor located down-gradient of a contaminant plume. EPA considered including an ecological risk screening assessment in Phase II. However, the available data on ecological benchmarks for these chemicals were too limited to support a meaningful screening. Therefore, ecological risks were not considered.

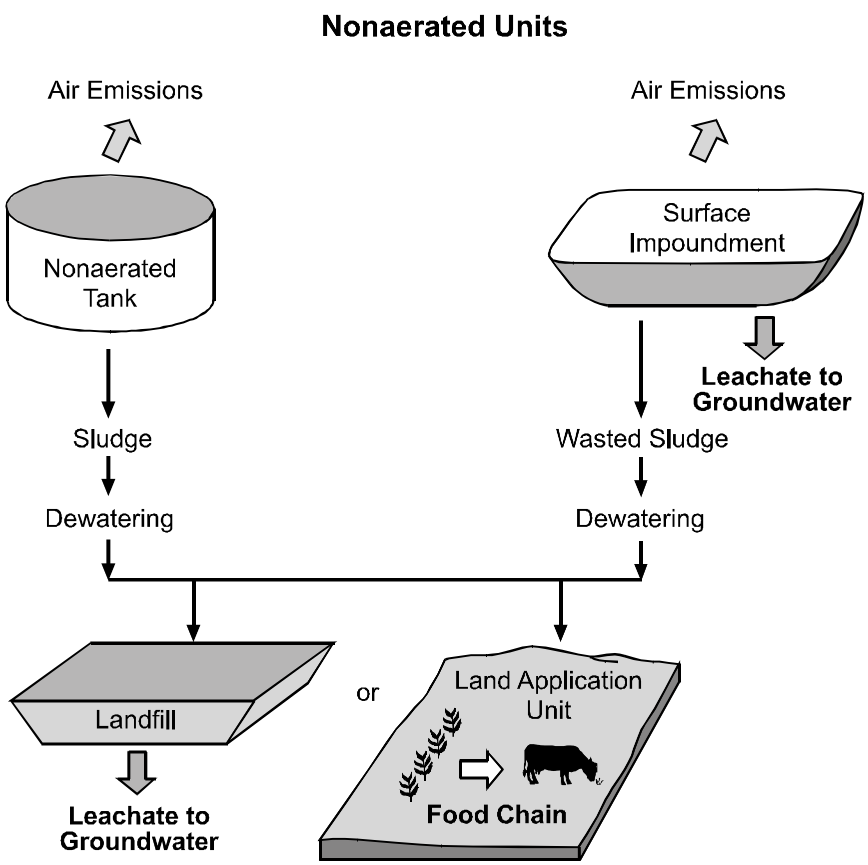

Figure 1-1. Schematic of nonaerated units modeled for Phase II. (Bold lettering represents the pathways evaluated and that, with the exception of 2-nitropropane, the air pathways screened out in Phase I and were therefore not evaluated in Phase II.)

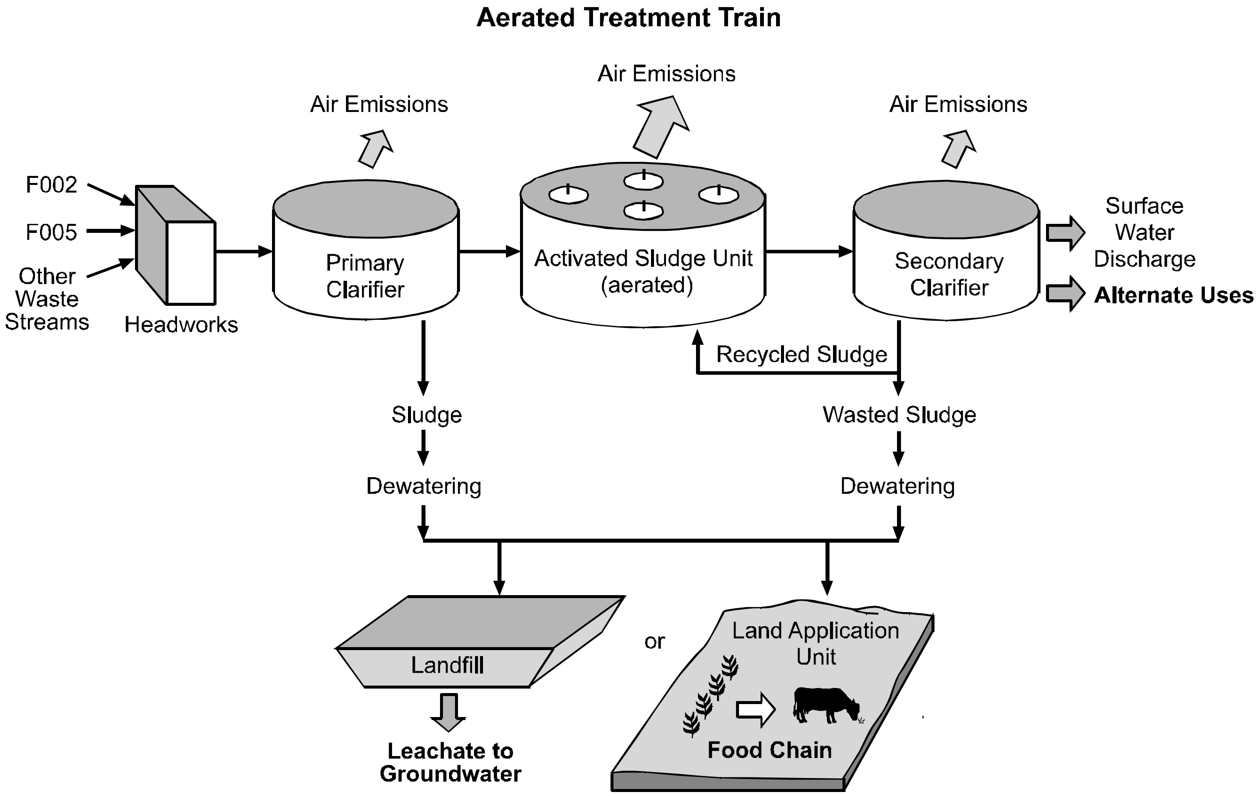

Figure 1-2. Schematic of aerated wastewater biological treatment train modeled for Phase II. (Bold lettering represents the pathways evaluated and that, with the exception of 2-nitropropane, the air pathways screened out in Phase I and were therefore not evaluated in Phase II.)

1.3 Key Results and Conclusions

EPA evaluated a variety of scenarios using differing input assumptions. Table 1-1 summarizes the Phase I results derived by comparing the previous modeling efforts with potential headworks exemption levels. The assumed input waste concentrations (one mg/L and 25 mg/L for carcinogens and noncarcinogens, respectively) for chemicals with shaded cells under any of the pathways exceeded the protective waste levels. An oral toxicity benchmark is not available for 2-nitropropane and together with other factors (e.g., low solvent use volume), EPA did not evaluate 2-nitropropane in Phase II. Only benzene, 2-ethoxyethanol, and 1,1,2-trichloroethane were evaluated in Phase II through the groundwater pathway.

Table 1-1. Summary of Phase I Results

Chemical	CAS Number	Air Pathway[a]	Groundwater Pathway[b]
Benzene	71432	pass	fail
2-Ethoxyethanol	110805	pass	fail
2-Nitropropane	79468	fail	N/A
1,1,2-Trichloroethane	79005	pass	fail

[a] Air pathway results are based on the comparison with the results reported in the Air Characteristics Study (U.S. EPA, 1999) for the aerated treatment tanks.
[b] Groundwater pathway results are based on the comparison with the health-based numbers (HBNs) previously used for the Industrial Waste Evaluation Model (IWEM) (U.S. EPA, 2002).
Shaded cells – Denote that the assumed waste concentrations are higher than the screening levels; chemicals were evaluated in the Phase II (except for 2-Nitropropane).

The chemicals evaluated in Phase II are relatively susceptible to degradation processes; therefore, once subjected to waste treatment that included aerated biological treatment, EPA estimated that for benzene and 2-ethoxyethanol little would remain to pose a risk in biologically-treated wastewater or sludge. The results for wastewater and sludge from the secondary clarifier show lower risks than the results for primary clarifier sludge (which comes before aerated biological treatment) and for nonaerated tanks and surface impoundments.

Table 1-2 summarizes the results for Phase II analyses. The calculated waste concentrations for benzene for all treatment units are above the protective levels for the nonaerated units. However, for benzene treated in the aerated biological units, the calculated concentrations are below the protective levels for all units except for the primary clarifier sludge going to a landfill (Figure 3-1).

Table 1-2 also depicts that the calculated waste concentrations for 1,1,2-TCA are higher than the protective levels for all treatment scenarios (Figures 1-1 and 1-3) under Phase II analyses. For 2-ethoxyethanol, Table 1-2 also shows that the calculated waste concentrations are below the protective levels for all scenarios under Phase II.

Table 1-2. Summary of Phase II Results[a]

	Nonaerated Units			Aerated Units		
Chemical	Wastewaters in Surface Impound-ment	SI Sludges in Landfills	Tank Sludges in Landfills	Secondary Clarifier Waste Water in SI	Primary Clarifier Sludges in Landfills	Secondary Clarifier Sludges in Landfills
Benzene	fail	fail	fail	pass	fail	pass
1,1,2-Trichloroethane	fail	fail	fail	fail	fail	fail
2-Ethoxyethanol	pass	pass	pass	pass	pass	pass

[a] Shaded cells denote that the calculated risks are above the target risk level of 1E-05 (failed).

The highest risk observed in the indirect analysis of sludge managed in land application units was 2E-5 (for nonaerated tank sludges containing both benzene and 1,1,2-trichloroethane). The highest HQ observed was 0.5 (for nonaerated tank sludge containing 2-ethoxyethanol).

1.4 Organization of this Report

This document describes the modeling approach and results of the headworks exemption risk assessment. The rest of this document is organized as follows:

- Section 2: Phase I Air and Groundwater Pathway Assessment
- Section 3: Phase II Groundwater Pathway Assessment
- Section 4: Indirect Pathway Assessment
- Section 5: References.

2.0 Phase I Air and Groundwater Pathway Assessment

In the Phase I analysis, EPA screened the air and groundwater risks from management of wastewaters containing benzene, 2-ethoxyethanol, 2-nitropropane, and 1,1,2-trichloroethane using previous modeling efforts. This section describes the Phase I analysis.

2.1 Methodology

2.1.1 Air Pathway

For the air pathway, EPA used results for aerated treatment tanks from the Air Characteristic Study (U.S. EPA, 1999) to compare with current headwork regulatory exemption levels. The Air Characteristic results are waste concentration estimates that would be protective of human health given inhalation exposures to each of the four chemicals as a result of volatilization from aerated tanks. The Air Characteristic Study included results for a variety of combinations of different treatment and storage tanks, receptor types, distances from the unit, and risk levels. The Study used ISC3ST (Industrial Source Complex Short-Term Model, Version 3), EPA's peer reviewed regulatory model, for the derivation of the results. EPA chose to compare the headworks exemption levels with Air Characteristic Study levels for aerated tanks, where adult residents are 150 m from the aerated tanks, the risk is equal to one-in-a-million, and the hazard quotient is equal to 0.25. The protective concentrations represent the constituent concentration at which 90 percent of adult receptors at the specified receptor distance would be protected to the specified risk threshold at 90 percent of the sites modeled.

2.1.2 Groundwater Pathway

For the groundwater pathway, the screening analysis compared waste concentration estimates taken from the Industrial Waste Evaluation Model (IWEM) (U.S. EPA, 2002). EPA compared the proposed headworks exemption levels with the leachate concentration threshold values (LCTVs) for these chemical constituents for landfills and surface impoundments from IWEM. The IWEM levels are based on the use of EPA's peer reviewed model, EPACMTP (EPA's Composite Model for Leachate Migration with Transformation Products) for the calculation of DAFs for each of the four chemicals with applicable headworks exemption levels. The DAFs represent the migration of leachate from the bottom of landfills to downgradient receptor wells to estimate risks. The EPACMTP (US EPA, 1996) has been reviewed by the EPA's Office of Research and Development and by the Science Advisory Board. EPACMTP has also been used by the EPA in various regulatory efforts. These efforts include: the petroleum refining listing determination; the inorganic chemicals listing determination, Soil Screening Levels for the Superfund program, and for the hazardous waste delisting program.

EPA identified waste concentration estimates that would be protective of human health given groundwater ingestion exposures to three of the solvents (benzene, 2-ethoxyethanol, and

1,1,2-trichloroethane). EPA also identified waste concentration estimates protective for inhalation during showering using contaminated ground water for each of the four solvents. The IWEM analysis considered no liner, compacted clay liner, and composite liner scenarios for both landfills and surface impoundments. These levels cover both direct ingestion of groundwater and inhalation while showering with groundwater. EPA selected to compare the headworks exemption levels with IWEM levels for unlined surface impoundments scenario with: a risk level of one-in-a-million, a hazard quotient of one, and a distance to a receptor of 150 meters.

2.2 Results

2.2.1 Air Pathway

Table 2-1 shows that for three of the solvents (benzene, 2-ethoxyethanol, and 1,1,2-trichloroethane), the protective levels for inhalation exposures are above the exemption level proposed for these chemicals. Thus, the existing standard of 1 ppm or 25 ppm would be protective for the air pathway for these chemicals under these scenarios. For 2-nitropropane, the protective levels are lower than the proposed exemption level for two of the three scenarios considered. Thus, this chemical poses a potential concern via the inhalation pathway from this protective screening analysis.

Table 2-1. Phase I Air and Groundwater Pathway Screening Results (mg/L)

Chemical	Waste Code	Headworks Exemption Level	Groundwater Ingestion[a]	Direct Inhalation[b]
Benzene (c)	F005	1	0.0027	3
2-Ethoxyethanol (nc)	F005	25	13	100,000
2-Nitropropane (c)	F005	1	N/A	0.04
1,1,2-Trichloroethane (c)	F002	1	0.0028	2

[a] Adult risk, unlined surface impoundment, 10^{-6} risk, HQ =1, receptor distance of 150 meters (IWEM, 2002)
[b] Adult risk, aerated tanks, 90 percent of receptors at 90 percent of sites protected, 150 m, 10^{-6} risk, HQ = 0.25 (Air Characteristic Study; EPA, 1999)
(c) is a carcinogen, (nc) is a non-carcinogen.

2.2.2 Groundwater Pathway

Table 2-1 presents the modeled protective groundwater levels (LCTVs) for an unlined surface impoundment based on the dilution attenuation factors (DAFs) calculated by the Industrial Waste Evaluation Model (IWEM). For 2-ethoxyethanol, the modeled protective level for groundwater exposure is higher than the proposed exemption level (i.e., the existing 25 ppm standard would be protective for this groundwater scenario). However, for benzene and 1,1,2-trichloroethane, the modeled protective levels are lower than the proposed exemption levels. EPA currently has very limited information available on ingestion risk from 2-NP. We also believe that the available information is not adequate to develop an oral benchmark for 2-NP for a rulemaking.

Tables 2-2 and 2-3 present the protective IWEM screening levels and HBNs for landfills and surface impoundments, respectively. The HBNs reflect a risk level of 1E-6 or an HQ of 1 and a dilution and attenuation factor (DAF) of 1 (that is, no fate and transport losses). The IWEM levels add a specific DAF for the liner, presence or absence of a liner, the type of liner, and waste management unit scenario. The IWEM levels represent both for the direct ingestion of groundwater and inhalation while showering with contaminated groundwater.

Table 2-2. Phase I Groundwater Pathway Results: HBNs and IWEM Screening Levels for Landfills (mg/L)

	HBN		No Liner		Compacted Clay Liner		Composite Liner	
Chemical	**Ingestion**	**Inhalation**	**Ingestion**	**Inhalation**	**Ingestion**	**Inhalation**	**Ingestion**	**Inhalation**
Benzene (NC)	---	1.9E-01	---	4.2E-01	---	5.0E-01[a]	---	5.0E-01[a]
Benzene (C)	1.8E-03	1.6E-03	3.9E-03	3.6E-03	1.1E-02	9.7E-03	5.0E-01[a]	5.0E-01[a]
2-Ethoxyethanol - (NC)	9.8E+00	2.9E+03	2.2E+01[d]	1.0E+03[b]	6.0E+01	1.0E+03[b]	1.0E+03[b]	1.0E+03[b]
1,1,2-Trichloroethane (NC)	9.8E-02	—	2.4E-01		7.3E-01		9.6E-01[b,c]	
1,1,2-Trichloroethane (C)	1.7E-03	1.1E-03	4.9E-04[c]	6.7E-04[c]	1.4E-02[c]	1.8E-03[c]	9.6E-01[b,c]	9.6E-01[b,c]
2-Nitropropane (NC)	---	3.3E-01	---	7.3E-01	---	2.0E+00	---	1.0E+03[b]
2-Nitropropane (C)	---	2.3E-05	---	5.1E-05	---	1.4E-04	---	3.7E-01

Waste concentration levels are based on risk = 1E-06 and HQ= 1.
Shaded cells indicate protective levels that are lower than the proposed exemption levels of 1 mg/L and 25 mg/L for carcinogens and non-carcinogens, respectively. NC - Non-carcinogen; C - Carcinogen
[a] Screening level is capped by the toxicity level of the chemical (the leachate concentration = DAF*HBN).
[b] Screening level is capped by 1,000 mg/L (Policy Issue) (the leachate concentration = DAF*HBN).
[c] Solubility (warning).
[d] Current headworks concentration level of 25 mg/L for non-carcinogens is, for practicable purposes, assumed to not exceed the screening level of 22 mg/L (i.e., 25 mg/L is equal to 22 mg/L)
Source: EPA, 2002.

Table 2-3. Phase I Groundwater HBNs and IWEM Screening Levels for Surface Impoundments (mg/L)

Chemicals	HBN		No Liner		Compacted Clay Liner		Composite Liner	
	Ingestion	Inhalation	Ingestion	Inhalation	Ingestion	Inhalation	Ingestion	Inhalation
Benzene (NC)	---	1.9E-01	---	2.5E-01	---	5.0E-01[a]	---	5.0E-01[a]
Benzene (C)	1.8E-03	1.6E-03	2.7E-03	2.5E-03	8.2E-03	7.5E-03	5.0E-01[a]	5.0E-01[a]
2-Ethoxyethanol - (NC)	9.8E+00	2.9E+03	1.3E+01	1.0E+03[b]	3.9E+01	1.0E+03[b]	1.0E+03[b]	1.0E+03[b]
1,1,2-Trichloroethane (NC)	9.8E-02	---	1.4E-01	---	4.5E-01	---	1.0E+03[b]	---
1,1,2-Trichloroethane (C)	1.7E-03	1.1E-03	2.8E-03	1.8E-03	8.9E-03	5.8E-03	1.0E+03[b]	1.0E+03[b]
2-Nitropropane (NC)	—	3.3E-01	—	4.4E-01	—	1.3E+00	---	1.0E+03[b]
2-Nitropropane (C)	---	2.3E-05	---	3.5E-05	---	1.4E-04	---	6.5E+00

Waste concentration levels are based on risk = 1E-06 and HQ= 1.
Shaded cells indicate protective levels that are lower than the proposed exemption levels of 1 mg/L and 25 mg/L for carcinogens and non-carcinogens, respectively.
NC - Non-carcinogen
C - Carcinogen
[a] Screening level is capped by the toxicity level of the chemical (the leachate concentration = DAF*HBN).
[b] Screening level is capped by 1,000 mg/L (policy issue) (the leachate concentration = DAF*HBN).
Source: EPA, 2002.

As shown in the above Tables 2-2 and 2-3, for 2-ethoxyethanol, the IWEM protective levels for groundwater exposure are higher than the proposed exemption level for all scenarios except surface impoundments with no liner. For benzene, the protective levels are lower than the proposed exemption levels for both ingestion and inhalation for no liner scenarios, indicating potential concern for these pathways. For 1,1,2-trichloroethane, the protective levels are lower than the proposed exemption levels for both ingestion and inhalation for no liner and all liner scenarios indicating potential concern for these pathways, with the exception of surface impoundments with composite liners. In addition, 1,1,2-TCA undergoes transformation to 1,1-dichloroethylene (1,1-DCE) due to hydrolysis while being transported in the subsurface environments. The transformation product (1,1-DCE) is more toxic than the parent compound (1,1,2-TCA) by approximately an order of magnitude. The transformation product has similar transport characteristics as the parent and, therefore, will likely result in lower protective levels compared with 1,1,2-TCA. For 2-nitropropane, only an inhalation benchmark is available. The protective levels are lower than the proposed exemption level for inhalation for all liner scenarios except the composite liner.

2.2.3 Conclusions

For benzene, 2-ethoxyethanol, and 1,1,2-trichloroethane, the air pathway appears to pose little concern at the proposed exemption levels. Therefore, the air pathway was not considered further in this analysis. The groundwater pathway for benzene, 2-ethoxyethanol, and 1,1,2-TCA does appear to pose potential risks in the Phase I analyses; thus, the groundwater pathway was evaluated in Phase II for these chemicals. Potential inhalation risks were estimated in this screening analysis for 2-nitropropane for both direct inhalation and shower inhalation exposures. Ingestion risks could not be characterized because of the absence of adequate health toxicity studies for 2-nitropropane. This solvent failed the air risk screen by a factor of 25 and the ground water risk screen (for shower inhalation) by a range of factors. Because of the large margin of failure for 2-nitropropane, we considered it unlikely that 2-nitropropane would pass a more robust Phase II type of analysis. Based on the large margin of failure in the Phase I screen and the extremely low reported usage that the Agency found for 2-nitropropane, we determined that continued analysis of 2-nitropropane was not likely to affect the regulatory status of these wastes significantly. Therefore, EPA did not analyze 2-nitropropane further in Phase II for either the air or groundwater pathways.

2.3 Discussion of Assumptions for the Phase I analysis

This section identifies the major assumptions and qualitatively describes how each may influence the results of the screening analysis.

- *Wastewater storage, disposal, and treatment (air and groundwater pathway).* This analysis assumed that the inlet concentration to the units modeled is equal to the proposed headworks exemption level (1 ppm or 25 ppm). The regulatory exemption concentration actually applies to the total concentration of any exempted spent solvents present in the wastewater being processed through the headworks of the facility's wastewater treatment system, and not to each solvent concentration individually.

- *Wastewater storage, disposal, and treatment (groundwater pathway).* The groundwater analysis assumed no reductions in concentration due to treatment. Clearly treatment does reduce concentrations, and to the extent that this occurs, it would result in a lower leachate concentration and lower risks. The Air Characteristic Study levels used for the air pathway analysis did model treatment effects on air emissions.

- *Sludge management (groundwater pathway).* EPA did not model physical and chemical processes that occur in the landfill managing the sludge. The analysis assumes that the landfill leachate concentration is equal to the exemption level. Thus, this assumption may lead to an overestimate of the risks.

- *Groundwater fate and exposure modeling.* The IWEM model used to estimate fate and transport in groundwater and exposure to groundwater is environmentally conservative with respect to exposure factors. For example, receptor wells are assumed to be located on the centerline of the contaminant groundwater plume. This may lead to an overestimate of the risks.

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3.0 Phase II Groundwater Pathway Analysis

In Phase II for the groundwater pathway, EPA performed a more realistic assessment of the groundwater risks from management of wastewaters for benzene, 2-ethoxyethanol, and 1,1,2-trichloroethane (1,1,2-TCA). In addition, EPA assessed groundwater risks from management of wastewater treatment sludge containing each of the constituents in landfills and land application units. Routes of exposure included: ingestion of contaminated ground water; inhalation of vapors during showering with contaminated ground water; and ingestion of contaminated food items.

EPA used the WATER 9 model (EPA, 1994) in this phase of the analysis. The WATER9 model, including the prediction of biodegradation and sludge sorption of organics, was used to estimate chemical emissions to the air, and wastewater and sludge concentrations within each unit of the treatment train.

The WATER9 model was developed by the EPA's Office of Air Quality Planning and Standards (OAQPS) for estimating emission losses from wastes and wastewaters. The WATER9 model consists of analytical expressions for estimating air emissions of individual waste constituents in wastewater collection, storage, treatment, and disposal facilities; a data base of chemical properties for the organic compounds; and procedures for obtaining reports of constituent fate of the chemical, including air emissions and treatment effectiveness. WATER9 is a significant upgrade of features previously obtained in the computer programs WATER8, Chem9, and Chemdat8. WATER9 contains a set of model units that can be used together in a project to provide a model for an entire facility. It provides separate emission estimates for each individual compound that is identified as a constituent of the wastes.

The WATER9 model has been extensively applied by the EPA's Office of Water and OAQPS for numerous regulations such as the Synthetic Organic Chemical Manufacturing Industry (SOCMI); Hazardous Organic National Emission Standards-for Hazardous Air Pollutants (HON); the Pharmaceutical Maximum Achievable Control Technology (MACT) Standard, the Publicly Owned Treatment Works (POTW) National Emission Standard for Hazardous Air Pollutants (NESHAP); the SOCMI New Source Performance Standard (NSPS); and the Industrial Wastewater (IWW) Control Techniques Guideline (CTG) . The documentation of the model and the verification by comparison to field tests are available (EPA-453/94-080A, OAQPS, RTP, NC, November 1994). WATER9, along with the documentation is available on the EPA website at: http://www.epa.gov/ttn/chief/software/water/. Additional documentation on the WATER9 model is available in the docket to this proposal.

EPA modeled wastewaters managed in both a nonaerated tank and unlined surface impoundment, and an aerated biological treatment system. EPA modeled sludges, generated by the various types of wastewater treatment, in landfills. Direct groundwater routes included exposure via ingestion of contaminated groundwater and inhalation of vapors from showering with contaminated groundwater. We used the data from 1997 Biennial Reporting System on waste volumes for modeling (U.S. EPA, December 2002).[1] For each waste management unit, multiple scenarios were modeled to characterize both central tendency risk and "high-end" risk. In all cases, the influent concentrations at the headworks were assumed to be the maximum exemption level allowable assigned (for carcinogens benzene and 1,1,2-TCA, 1 ppm, and for non-carcinogen 2-ethoxyethanol, 25 ppm). The target risk level was set at 1E-5 (one chance in 100,000) for carcinogens and the target hazard quotient was set at 1 for non-carcinogens. In addition, EPA assumed that sludges from the primary and secondary clarifiers in the aerated biological treatment train were managed in separate landfills, rather than being mixed prior to disposal.

3.1 Methodology for the Groundwater Pathway

3.1.1 Scenarios

EPA conducted the Phase II assessment for nonaerated units and an aerated biological wastewater treatment train, as shown in Figures 1-1 and 1-2. For nonaerated wastewater units, EPA modeled a storage tank and an unlined surface impoundment. EPA modeled wastewater treatment using a treatment train consisting of a primary clarifier, an activated sludge unit, and a secondary clarifier. The activated sludge unit is aerated and designed to optimize aerobic biodegradation of contaminants. The clarifiers are not aerated.

Figures 1-1 and 1-2 show, in bold, the pathways assessed for the groundwater and indirect analyses. For groundwater, the following pathways were considered:

- Leachate to groundwater from nonaerated, unlined surface impoundment,
- Leachate to groundwater from landfill managing sludge from nonaerated storage tank,
- Leachate to groundwater from landfill managing sludge from surface impoundment,
- Leachate to groundwater from alternative uses of effluent from secondary clarifier,
- Leachate to groundwater from landfill managing sludge from primary clarifier,

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[1] EPA used the 1997 BRS data because that was the most recent data year reporting available for public access to query at http://www.epa.gov/enviro/html/brs/brs_query.html. EPA queried the BRS for data on F002 (for 1,1,2-trichloroethane) and F005 (for benzene, 2-ethoxyethanol, and 2-nitropropane) at facilities that generated or managed these classes of RCRA hazardous waste spent solvents. The data from the BRS do not reveal which solvent is linked to a specific waste code. To screen for a "high end" exposure analysis, EPA based the input parameters on the facility that is the 90th percentile in size for the given waste code (i.e., that only ten percent of the facilities are larger. (See Database Background Document for the Headworks Exemption Proposed Rule, 2002) for distribution of volumes).

- Leachate to groundwater from landfill managing sludge from secondary clarifier, and

- Ingestion of crops and meat products raised on land receiving contaminated sludges from nonaerated storage tank and surface impoundments.

The tank units (both the nonaerated tank and all three units in the aerated treatment train) are assumed not to leak or otherwise leach to groundwater. Wastewater from the secondary clarifier is assumed to reach groundwater through alternative uses (e.g., temporary on-site management of secondary clarifier effluent in a surface impoundment prior to discharge under a NPDES permit).

EPA evaluated the exposure pathways using a variety of scenarios intended to capture the range of exposures from central tendency to high end. To define "high end," EPA first considered the components of the risk assessment: source characterization, fate and transport, exposure, and toxicity. Each of these components encompasses one or more input variables. To model a high-end scenario, EPA set one or more inputs in two of the four components to high-end values.

For fate, exposure, and toxicity, only one variable was selected to be varied for each scenario. For fate, the chemical-specific DAFs in groundwater generated in IWEM (EPA, 2002) were used as a surrogate for a chemical's fate and transport to a receptor well in groundwater. The DAF reflects the extensive modeling done for the development of the Industrial D Waste Management Guidance. For exposure, the critical variable is exposure duration; the exposure calculation uses other exposure factors, including body weight, inhalation rate or water consumption rate, and exposure frequency. However, none of these vary over as great a range as exposure duration, so they will have less effect on the results. For toxicity, the critical variable is the health benchmark for either oral or inhalation exposure. In this analysis, toxicity varies only for benzene. The source for the toxicity benchmarks is IRIS (Integrated Risk Information System) (EPA, 2002; http://www.epa.gov/iris/).

The source component encompasses a much larger number of input variables than the other components. Because of the relationship among critical variables, and because the model is not sensitive to all parameters that describe the source component, the scenarios were designed in terms of combinations of variables that were consistent with engineering principles. Thus, within any scenario for which source was set to high end, EPA defined two to four sub-scenarios reflecting high-end source characterization using combinations of the critical source variables set to high-end and central-tendency values. For this analysis, the variables that were varied for the nonaerated treatment train and for the aerated treatment train are described in Appendix A. In all scenarios, the inlet concentration to the unit or treatment system was set to the maximum allowable concentration under the headworks exemption: 1 ppm for carcinogens and 25 ppm for non-carcinogens.

Table 3-1 summarizes the main scenarios modeled. Some of the chemicals are not affected by all components of the risk paradigm. Exposure affects the risk results only for carcinogens. This is because, for non-carcinogens, exposure duration is always equal to the averaging time; a change in one cancels out the corresponding change in the other, so the risk results are not affected. For carcinogens, the averaging time is fixed to correspond to assumptions made in developing the cancer slope factors; a change in exposure duration does affect the risk results for carcinogens. Therefore, exposure duration was not varied for 2-ethoxyethanol, which is a non-carcinogen. Similarly, toxicity is not typically varied. EPA has established a single value for most health benchmarks used in risk assessments. However, the toxicity data for benzene support a range of values for the oral and inhalation cancer slope factors. Thus, toxicity was varied between the low-end and high-end of the range for benzene, but not for 2-ethoxyethanol or 1,1,2-trichloroethane.

Table 3-1-A. Summary of Scenarios Modeled for 2-Ethoxyethanol

	A	B
Source	central	high
Fate	central	high
Exposure	NA	NA
Toxicity	NA	NA

Table 3-1-B. Summary of Scenarios Modeled for 1,1,2-Trichloroethane

	A	B	C	D
Source	central	high	high	central
Fate	central	high	central	high
Exposure	central	central	high	high
Toxicity	NA	NA	NA	NA

Table 3-1-C. Summary of Scenarios Modeled for Benzene

	A	B	C	D	E	F	G
Source	central	high	high	central	high	central	central
Fate	central	high	central	high	central	high	central
Exposure	central	central	high	high	central	central	high
Toxicity[3]	central	central	central	central	high	high	high

Notes for Table 3-1:
NA = Not applicable; does not apply.
Maximum of two components set to high-end per scenario.
Quantitative oral risk estimate is presented as a range of 3.5E-2 CSF (per mg/kg-d) to 5.5E-2 CSF (per mg/kg-d) (U.S. EPA, 2001b). We used the low-end and high-end values of the range as central tendency and high end values, respectively.

Tables 3-2, 3-3, and 3-4 present the input values for the scenarios modeled for benzene, 2-ethoxyethanol, and 1,1,2-trichloroethane, respectively. These tables include the actual input values for fate (DAF), exposure (exposure duration), and toxicity (oral and inhalation cancer slope factor).

The main modeling scenarios were assigned letters (as shown in Table 3-1), the subscenarios for source were assigned numbers. Some numbers are missing because some scenarios were dropped because they had too many variables set to high end after the scenario numbering was fixed. Tables 3-5 and 3-6 present the source subscenarios for nonaerated and aerated units, respectively. These tables present the values only for critical source parameters. Details of all input values used for source modeling are presented in Appendix A. In addition, Appendix A of the report indicates that Attachment A.2 includes all of the source parameters for each of the runs. Tables 3-5 and 3-6 also provide the Run ID in the left most column that corresponds to the Run ID in Attachment A.2, and defines exactly what the settings were for each run. In addition to this information, one can also crosswalk the runs against scenarios A through D in Table 3-4 as the sixth column (Source) indicates which runs are relevant to that scenario.

The DAF values were varied (distributions that were generated previously for IWEM) between 50th percentile (central tendency) and 90th percentile (high end). DAF values differ between surface impoundments and landfills. In addition, the DAF also varies over time and for consistency, EPA chose a DAF corresponding to the exposure duration. Thus, the DAFs vary depending on whether exposure duration is set to central tendency or high end.

For exposure duration, values of 9 years (central tendency) and 30 years (high end) were chosen; these values represent the median and 95th percentiles, respectively, for the number of years the U.S. population resides at a location (EPA, 1997). For toxicity, all benchmarks used in this analysis are found in the IRIS (Integrated Risk Information System) (U.S. EPA, 2001-b). For benzene, the low end of the benchmark range presented in the IRIS was used for central tendency, and the upper end of the range was used for high end.

Table 3-2. Scenarios for Benzene

Nonaerated Units

Scenario	Source	Fate	Exposure	Toxicity	Source[a]	Fate DAF SI	Fate DAF LF	Exposure ED (yr)	Toxicity oral CSF (per mg/kg/d)	Toxicity inhal CSF (per mg/kg/d)	Comments
Central-Tendency Scenario											
A	CT	CT	CT	CT	Run 2	12.5	93.5	9	3.5E-02	5.0E-06	
High-End Scenarios											
B	HE	HE	CT	CT	Runs 1, 3-5	1.4	2.2	9	3.5E-02	5.0E-06	Maximum HE
C	HE	CT	HE	CT	Runs 1, 3-5	14.9	93.5	30	3.5E-02	5.0E-06	
D	CT	HE	HE	CT	Run 2	1.6	2.2	30	3.5E-02	5.0E-06	
E	HE	CT	CT	HE	Runs 1, 3-5	12.5	93.5	9	5.5E-02	7.8E-06	Maximum HE
F	CT	HE	CT	HE	Run 2	1.4	2.2	9	5.5E-02	7.8E-06	
G	CT	CT	HE	HE	Run 2	14.9	93.5	30	5.5E-02	7.8E-06	

Aerated Treatment Train

Scenario	Source	Fate	Exposure	Toxicity	Source[b]	Fate DAF SI	Fate DAF LF	Exposure ED (yr)	Toxicity oral CSF (per mg/kg/d)	Toxicity inhal CSF (per mg/kg/d)	Comments
Central-Tendency Scenario											
A	CT	CT	CT	CT	Run 7	12.5	93.5	9	3.5E-02	5.0E-06	
High-End Scenarios											
B	HE	HE	CT	CT	Runs 8 and 9	1.4	2.2	9	3.5E-02	5.0E-06	
C	HE	CT	HE	CT	Runs 8 and 9	14.9	93.5	30	3.5E-02	5.0E-06	
D	CT	HE	HE	CT	Run 7	1.6	2.2	30	3.5E-02	5.0E-06	Maximum HE
E	HE	CT	CT	HE	Runs 8 and 9	12.5	93.5	9	5.5E-02	7.8E-06	Maximum HE
F	CT	HE	CT	HE	Run 7	1.4	2.2	9	5.5E-02	7.8E-06	
G	CT	CT	HE	HE	Run 7	14.9	93.5	30	5.5E-02	7.8E-06	

[a] See Table 3-5 for definition of runs
[b] See Table 3-6 for definition of runs
Shaded cells are high-end values
Key to abbreviations:
CT = central tendency
HE = high end
DAF = dilution-attenuation factor
SI = surface impoundment
LF = landfill
ED = exposure duration
CSF = cancer slope factor

Table 3-3. Scenarios for 2-Ethoxyethanol

Nonaerated Units

						Fate		Exposure	Toxicity[c]		
						DAF		ED	oral CSF	inhal CSF	
Scenario	Source	Fate	Exposure	Toxicity	Source[a]	SI	LF	(yr)	(per mg/kg/d)		Comments
Central-Tendency Scenario											
A	CT	CT	NA	NA	Run 2	12.3	95.5	NV	0.4	0.2	
High-End Scenarios											
B	HE	HE	NA	NA	Runs 1, 3-5	1.4	2.2	NV	0.4	0.2	Maximum HE

Aerated Treatment Train

						Fate		Exposure	Toxicity*		
						DAF		ED	oral CSF	inhal CSF	
Scenario	Source	Fate	Exposure	Toxicity	Source[b]	SI	LF	(yr)	(per mg/kg/d)		Comments
Central-Tendency Scenario											
A	CT	CT	NA	NA	Run 7	12.3	95.5	NV	0.4	0.2	
High-End Scenario											
B	HE	HE	NA	NA	Runs 8 and 9	1.4	2.2	NV	0.4	0.2	Minimum & Maximum HE

[a]See Table 3-5 for definition of runs
[b]See Table 3-6 for definition of runs
[c]Does not vary for 2-ethoxyethanol

Shaded cells are high-end values

Key to abbreviations:
CT = central tendency   DAF = dilution-attenuation factor   LF = landfill   RfD = reference dose   NV = not varied
HE = high end   SI = surface impoundment   ED = exposure duration   RfC = reference concentration

Table 3-4. Scenarios for 1,1,2-Trichloroethane

Nonaerated Units

Scenario	Source	Fate	Exposure	Toxicity	Source[a]	Fate: DAF SI	Fate: DAF LF	Exposure: ED (yr)	Toxicity[c]: oral CSF (per mg/kg/d)	Toxicity[c]: inhal CSF (per mg/kg/d)	Comments
Central-Tendency Scenario											
A	CT	CT	CT	CT	Run 2	14	127	9	5.7E-02	5.6E-02	
High-End Scenarios											
B	HE	HE	NA	NA	Runs 1, 3-5	1.4	2.2	9	5.7E-02	5.6E-02	Maximum HE
C	HE	CT	HE	NA	Runs 1, 3-5	16.9	127	30	5.7E-02	5.6E-02	Maximum HE
D	CT	HE	HE	NA	Run 2	1.6	2.5	30	5.7E-02	5.6E-02	

Aerated Treatment Train

Scenario	Source	Fate	Exposure	Toxicity	Source[b]	Fate: DAF SI	Fate: DAF LF	Exposure: ED (yr)	Toxicity*: oral CSF (per mg/kg/d)	Toxicity*: inhal CSF (per mg/kg/d)	Comments
Central-Tendency Scenario											
A	CT	CT	CT	CT	Run 7	14	127	9	5.7E-02	5.7E-02	
High-End Scenarios											
B	HE	HE	CT	NA	Runs 8 and 9	1.4	2.5	9	5.7E-02	5.6E-02	
C	HE	CT	HE	NA	Runs 8 and 9	16.9	127	30	5.7E-02	5.6E-02	Maximum HE
D	CT	HE	HE	NA	Run 7	1.6	2.5	30	5.7E-02	5.6E-02	Maximum HE

[a] See Table 3-5 for definition of runs
[b] See Table 3-6 for definition of runs
[c] Does not vary for 1,1,2-trichloroethane

Shaded cells are high-end values

Key to abbreviations:
CT = central tendency
HE = high end
DAF = dilution-attenuation factor
SI = surface impoundment
LF = landfill
ED = exposure duration
CSF = cancer slope factor

Table 3-5. Source Scenario Detail for Nonaerated Units

Run #	Overall type	Biomass	Flow	Capacity	Solids	Biomass (g/L)	Flow (L/s)	Capacity		Solids	
								Tank (m3)	SI (m3)	Solids content (wt fraction)	Fraction solids removed (fraction)
1	HE	HE	CT	HE	CT	0	0.0079	1.9	4.3	0.16	0.63
2	CT	CT	CT	CT	CT	0.03	0.0079	15	11	0.16	0.63
3	HE	HE	HE	CT	CT	0	2.9	17	2120	0.16	0.63
4	HE	CT	HE	HE	CT	0.03	2.9	2.3	113	0.16	0.63
5	HE	HE	CT	CT	HE	0	0.0079	15	11	0.5	0.99

Shaded cells are high-end values

Key to abbreviations:
CT = central tendency SI = surface impoundment
HE = high end

Notes:

Biomass: Lower biomass results in less biodegradation, which results in more high-end contaminant levels in wastewater and leachate
0.03 g/L is the 75th percentile of all Surface Impoundment Study (SIS) values (includes both aerated and nonaerated units)

Flow: Higher flow results in waste moving more quickly through the unit and lower losses, which results in more high-end contaminant levels in wastewater and leachate
0.0079 L/s is the 50th percentile from the Biennial Reporting System (BRS) data on waste codes F002 and F005
2.9 L/s is the 90th percentile from the BRS data

Capacity: Lower/smaller capacity results in waste moving more quickly through the unit and lower losses, which results in more high-end contaminant levels in wastewater and leachate
Values are from either the tank database or the SIS and reflect midrange or small volumes for similar flows

Solids: Higher values result in more high-end contaminant levels in sludge, but have little effect on wastewater and leachate concentrations for these chemicals because only a small fraction partitions to sludge
Central-tendency values are 50th percentile from SIS
High-end values are 90th percentile from SIS
Solids content and fraction solids removed are related and were changed as a pair

Table 3-6. Source Scenario Detail for Aerated Treatment Train

					Residence time (hr)			Capacity (m^3)		
Run #	Overall type	Flow	Residence time	Flow (L/s)	Primary clarifier	Activated sludge	Secondary clarifier	Primary clarifier	Activated sludge	Secondary clarifier
7	CT	CT	CT	0.12	3.6	4.3	2.9	1.6	3.5	2.4
8	HE	HE	CT	2.9	2.6	4.4	2.4	27	91	50
9	HE	CT	HE	0.12	3.6	2.0	2.9	1.6	1.6	2.4

Shaded cells are high-end values

Key to abbreviations:
CT = central tendency
HE = high end

Notes:

Flow: Higher flow results in waste moving more quickly through the system and lower losses, which results in more high-end contaminant levels in wastewater and leachate
0.12 L/s is the smallest feasible flow from engineering design principles
0.12 L/s is about 75th percentile from the BRS data
2.9 L/s is the 90th percentile from the BRS data

Res time: Lower residence time results in waste moving quickly through the system and lower losses, which results in more high-end contaminant levels in wastewater and leachate
Based on engineering judgment
Only residence time in the activated sludge unit is varied, not the clarifiers, because the activated sludge unit is where most of the air emissions and all of the biodegradation occur, so it is the most sensitive to residence time

Capacity: This is determined by flow and residence time; it is not an independent variable
The flow used to determine capacity in the activated sludge and secondary clarifier is greater than the flow shown in the table because it includes recycle flow from the secondary clarifier back through the activated sludge unit

3.1.2 Modeling Approach

The groundwater analysis was done in two parts: source modeling and groundwater fate and exposure modeling. These two parts are discussed in the next sections.

3.1.2.1 Source modeling. EPA reviewed models that could be used to estimate concentrations of chemicals in leachate and sludge for storage and treatment tanks, surface impoundments, and aerated biological treatment systems. EPA used the following criteria to identify models for consideration:

- *Waste management units modeled.* Models must be able to model surface impoundments, tanks, and aerated treatment systems.
- *Scientific basis.* Models must be based on sound science that can stand up to technical review for this particular application, including the capability to account for degradation within the unit.
- *Model in the public domain.* Models must be available to the general public.
- *Level of review.* Models must have been subject to some independent review, preferably by industry, other members of the public, or peer-review experts.
- *Verification.* The model calculations should be independently verified to ensure that the model produces accurate calculations in accordance with the model design.
- *Documentation.* Model science must be documented, and the documentation must be publically available.

Three models met these criteria and were considered for this analysis: WATER8, WATER9, and the tank and surface impoundment model developed for the Surface Impoundment Study (SIS) (hereinafter referred to as the “SIS model”). These models are described briefly below.

- *WATER8* is a steady-state analytical model for estimating compound-specific air emissions from wastewater collection and treatment systems. It can only run one unit at a time and does not account for adsorption to solids or hydrolysis. It does account for biodegradation.
- *WATER9* is also a steady-state model for estimating compound-specific air emissions from wastewater collection and treatment systems. WATER9 includes several upgrades of features previously obtained in WATER8 and the related programs CHEM9 and CHEMDAT8. WATER9 can model an entire treatment train of connected units. WATER9 can calculate chemical adsorption to solids; it also accounts for biodegradation. It does not account for hydrolysis.

- The *SIS model* contains models for an aerated tank and a surface impoundment module. The modules employ a mass-balance approach that takes into consideration contaminant removal by volatilization, biodegradation, hydrolysis, leaching, and partitioning to solids. The modules can also estimate infiltration rate and contaminant leachate flux rates (for surface impoundments only) and suspended solids removal (settling) efficiency. The aerated tank module calculates only volatile emissions and is assumed to have an impervious bottom so that there is no contaminant leaching.

The following general factors were considered when reviewing the models:

- *Model outputs.* The model should be able to calculate both a sludge concentration and a leachate concentration for each chemical. Given the chemical properties of the chemicals to be modeled and their low tendency for adsorption to solids, for purposes of this analysis, it was determined that setting the leachate concentration equal to the concentration of chemical in the wastewater in the unit was an acceptable assumption.

- *Waste management units modeled.* The model should be able to model a treatment train with at least one aerated unit.

- *Validation.* The model results should have been successfully compared with field data or the results of other similar models.

- *Ease of use.* The model should be able to run quickly and should be easy to run using a reasonable number of data inputs that can be easily obtained or estimated.

Table 3-7 summarizes how the three models compare on these factors. Based on this comparison, EPA selected WATER9 to model the wastewater units. Some minor modifications were made to WATER9 to facilitate the output of needed specific sludge concentrations. See Appendix B for details.

Table 3-7. Comparison of Models for Source Modeling

Factor	WATER8	WATER9	SIS Model
Calculates sludge concentration?	Yes	Yes	Yes
Calculates leachate concentration?	No[a]	No[a]	Yes
Models treatment train?	No	Yes	No
Validated?	Yes	Yes[b]	No
Easy and fast to use?	Yes	Yes	No

[a] Assume leachate concentration equals wastewater concentration in unit when using these models
[b] Except absorption routine

3.1.2.2 Groundwater modeling. EPA used previously generated results from IWEM (U.S. EPA, 2002) to conduct the groundwater modeling analyses. IWEM is a groundwater evaluation tool that considers both ingestion of groundwater and exposure to groundwater contaminants by inhalation during showering. IWEM's look-up tables include HBNs and DAFs for numerous chemicals. IWEM HBNs are based on a receptor 150 m from the source, on the center line of the contaminant plume.

The HBNs are levels in a specific medium (e.g., water or air) that are not expected to result in a risk or HQ greater than a specified target risk or HQ via a specified pathway. HBNs are calculated from the health benchmark, a target risk or HQ, and exposure factors specific to the pathway. HBNs are both chemical- and pathway-specific. IWEM includes HBNs for direct ingestion of groundwater and for inhalation of groundwater contaminants while showering. The HBN calculations are documented in the IWEM documentation (U.S. EPA, 2002).

The HBNs in IWEM are based on an exposure duration of 30 years and a target risk of 1E-6 (or HQ of 1). Because the carcinogenic HBN is linear with exposure duration and risk, the IWEM HBNs can easily be adjusted to other exposure durations or target risk levels as follows:

$$HBN_{adj} = HBN_{IWEM} \ x \ \frac{30}{ED} \ x \ \frac{Risk}{1E-6}$$

where

HBN_{adj}	=	HBN adjusted to desired exposure duration or target risk
HBN_{IWEM}	=	HBN from IWEM (based on 30-year exposure duration and 1E-6 risk)
ED	=	desired exposure duration (yr)
Risk	=	desired target risk (unitless).

For benzene, the IWEM HBN is based on the high-end cancer slope factor. It can be adjusted for a different cancer slope factor (e.g., the midpoint of the IRIS range for benzene) following the same method:

$$HBN_{adj} = HBN_{HE} \ x \ \frac{CSF_{HE}}{CSF}$$

where

HBN_{adj}	=	HBN adjusted to desired CSF
HBN_{HE}	=	HBN based on high-end cancer slope factor
CSF_{HE}	=	high-end cancer slope factor (5.5E-2 per mg/kg-d for oral exposure and 7.8E-6 per mg/kg-d for inhalation exposure)
CSF	=	midrange cancer slope factor (3.5E-2 per mg/kg-d for oral exposure and 5E-6 per mg/kg-d for inhalation exposure)

The DAFs in IWEM were developed using EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP). EPACMTP generates a distribution of expected DAF values. IWEM includes 50^{th} and 90^{th} percentile DAFs from those distributions.

IWEM also includes DAFs for two durations, 9 years and 30 years, chosen to correspond to commonly used central-tendency and high-end exposure durations.

Multiplying the HBN by the DAF produces a concentration in leachate that would not be expected to exceed the target risk level associated with the HBN. EPA compared these levels with modeled leachate concentrations to determine whether the chemical was of concern. A ratio greater than 1 of modeled concentration to the IWEM concentration indicates potential concern (risk or HQ greater than the target risk or HQ). A ratio less than or equal to 1 indicates that the risk or HQ is less than or equal to the target risk or HQ.

3.2 Results for the Groundwater Pathway

Figures 3-1 through 3-3 present the results based on a target risk of 1E-5 and a target HQ of 1 for benzene, 2-ethoxyethanol, and 1,1,2-trichloroethane, respectively. Each mark represents the result for a single scenario, either ingestion or inhalation. The open marks indicate central-tendency results (one for ingestion and one for inhalation); the closed marks indicate high-end results. The heavy rule at a ratio of 1 indicates the point at which the calculated risk or HQ equals the target risk of 1E-5 or the target HQ of 1.

Tables 3-8 through 3-10 present the range of the results shown in the figures in tabular form. Shaded values exceed a ratio of 1. For those values, the scenario that resulted in that value is noted. The scenarios are detailed in Tables 3-2 through 3-6. Appendix C presents the detailed groundwater results for all scenarios.

As expected, the risks are greater from nonaerated units and units before the aerated activated sludge unit in the aerated biological treatment train than for the aerated activated sludge unit or units after the activated sludge unit in the aerated biological treatment train. None of the scenarios result in risk of concern for 2-ethoxyethanol. For benzene and 1,1,2-trichloroethane, the secondary clarifier (both alternative uses of the wastewater and sludge management) shows no risks of concern. The nonaerated unlined surface impoundment and tank units and the primary clarifier sludge show risks of concern for a few scenarios. Those scenarios are mostly the ones in which source and fate parameters are set to high-end values (Scenario B).

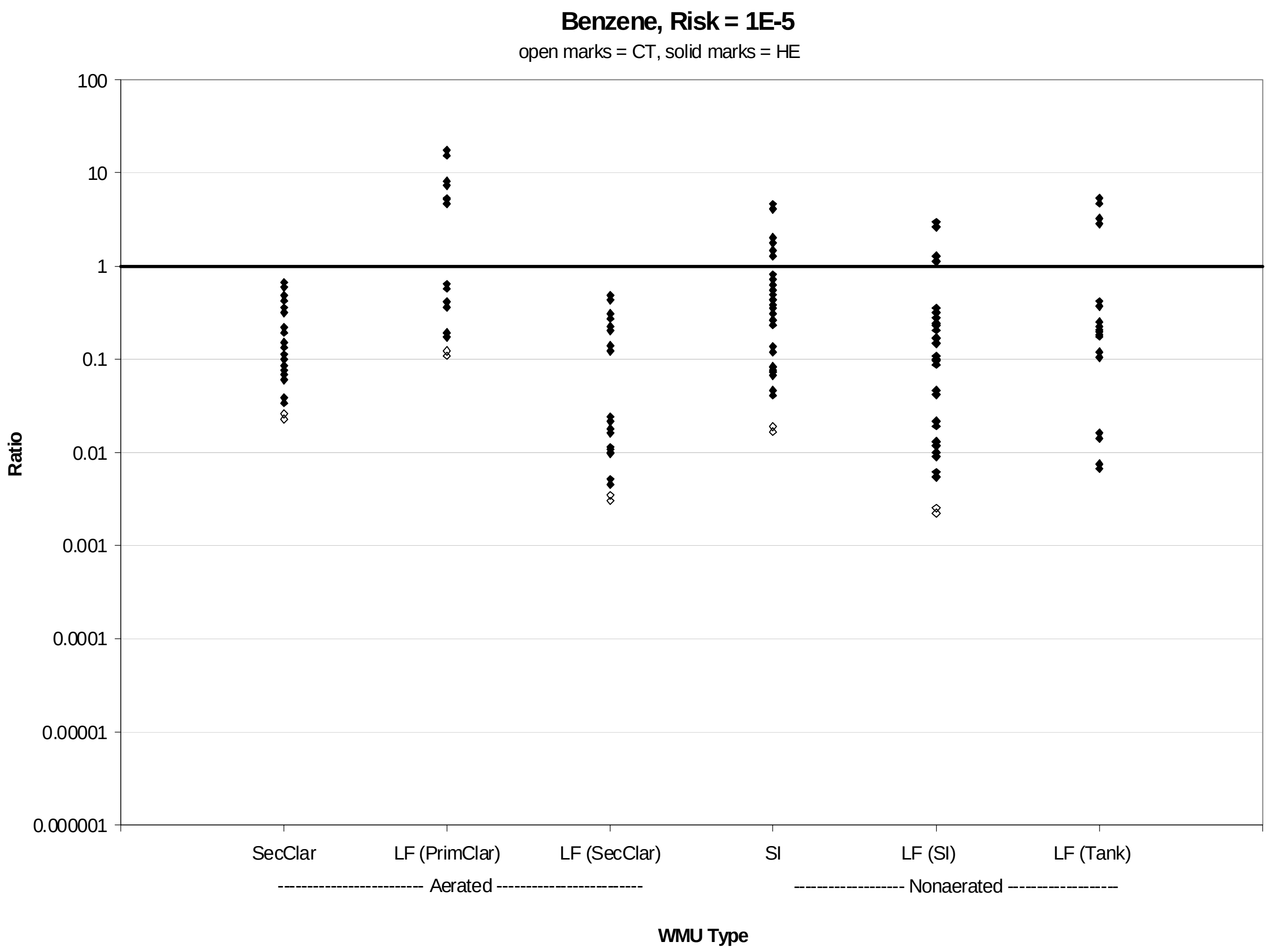

Figure 3-1. Groundwater results for benzene: ratio of calculated risk to 1E-5.

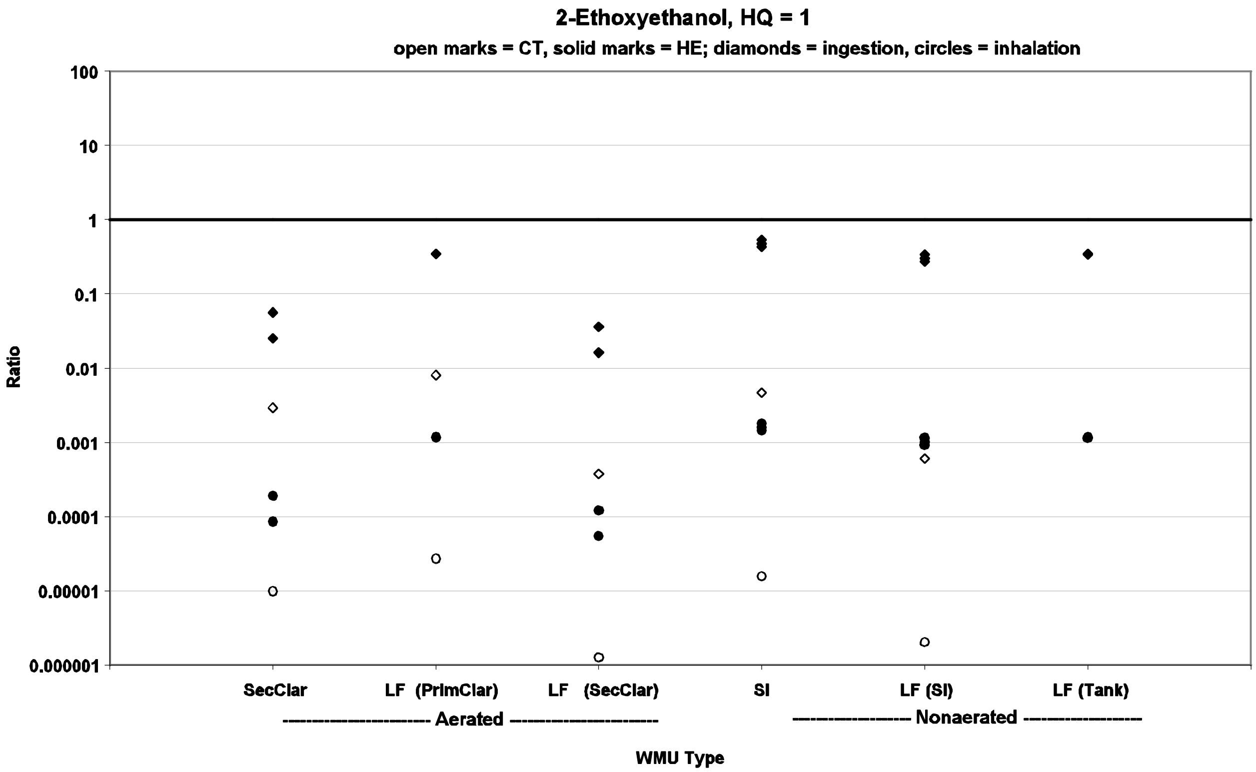

Figure 3-2. Groundwater results for 2-ethoxyethanol: ratio of calculated HQ to 1.

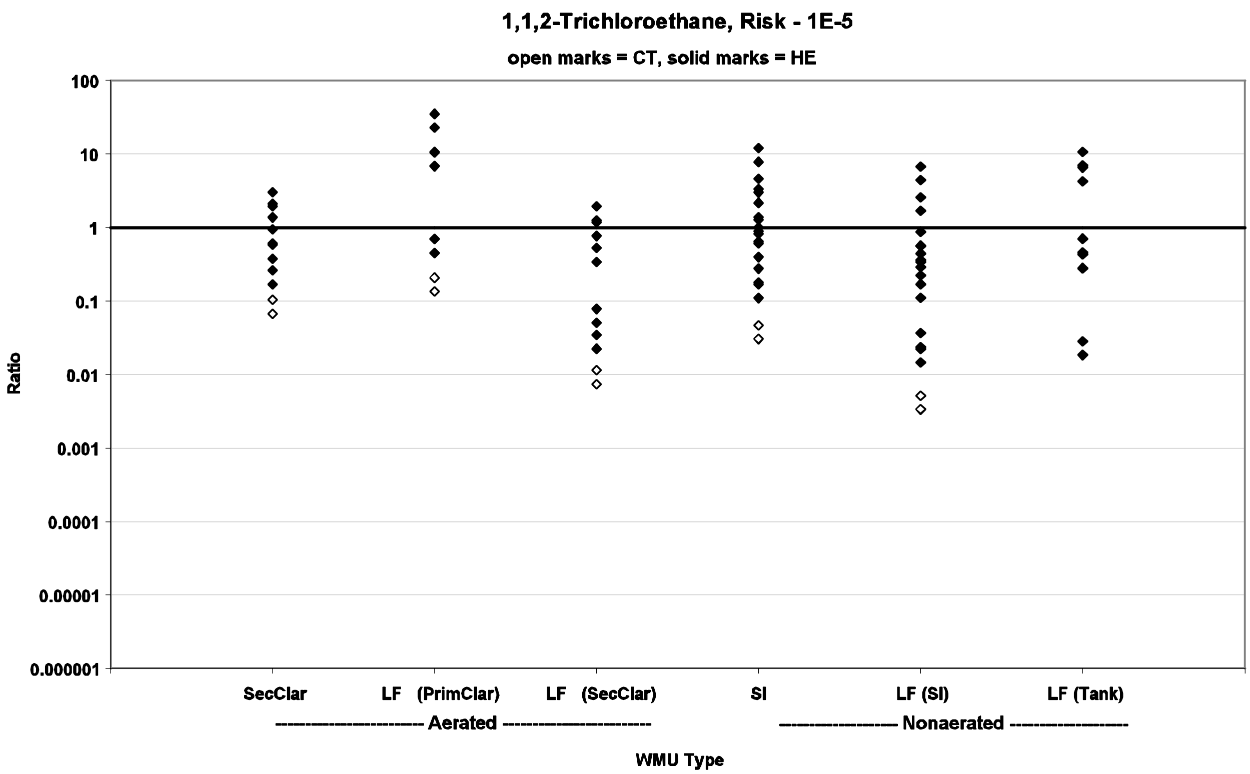

Figure 3-3. Groundwater results for 1,1,2-trichloroethane: ratio of calculated risk to 1E-5.

Table 3-8. Summary of Groundwater Results for Benzene: Ratios of Calculated Risk to Target Risk

Results for Benzene

Risk = 1E-5, Aerated Treatment Train

WMU	Pathway	Ingestion			Inhalation		
		CT	Min HE	Max HE	Ct	Min HE	Max HE
Secondary Clarifier	alternate uses	0.02	0.03	0.6	0.03	0.04	0.7
Landfill (primary clarifier sludge)	leachate to GW	0.1	0.2	16 D7	0.1	0.2	18 D7
Landfill (secondary clarifier sludge)	leachate to GW	0.003	0.005	0.4	0.003	0.005	0.5

Risk = 1E-5, Nonaerated Units

WMU	Pathway	Ingestion			Inhalation		
		CT	Min HE	Max HE	Ct	Min HE	Max HE
Surface Impoundment	leachate to GW	0.02	0.04	4 B4	0.02	0.05	5 B4
Landfill (SI sludge)	leachate to GW	0.002	0.006	3 B4	0.003	0.006	3 B4
Landfill (tank sludge)	leachate to GW	NA	0.007	5 B3	NA	0.008	5 B3

Shaded values to not screen out
The code following values that do not screen out indicates the scenario that resulted in the displayed result
The letter refers to the overall scenario, and the number to the specific source scenario within the lettered scenarios
Key to abbreviations: CT = central tendency; HE = high end; GW = groundwater; SI = surface impoundment; NA = not applicable; WMU = waste management unit

Table 3-9. Summary of Groundwater Results for 2-Ethoxyethanol: Ratios of Calculated HQ to Target HQ

HQ = 1, Aerated Treatment Train

WMU	Pathway	Ingestion			Inhalation		
		CT	Min HE	Max HE	Ct	Min HE	Max HE
Secondary Clarifier	alternate uses	0.003	0.03	0.06	0.00001	0.00009	0.0002
Landfill (primary clarifier sludge)	leachate to GW	0.008	0.3	0.3	0.00003	0.001	0.001
Landfill (secondary clarifier sludge)	leachate to GW	0.0004	0.02	0.04	0.000001	0.00005	0.0001

Risk = 1E-5, Nonaerated Units

WMU	Pathway	Ingestion			Inhalation		
		CT	Min HE	Max HE	Ct	Min HE	Max HE
Surface Impoundment	leachate to GW	0.005	0.4	0.5	0.00002	0.001	0.002
Landfill (SI sludge)	leachate to GW	0.0006	0.3	0.3	0.000002	0.0009	0.001
Landfill (tank sludge)	leachate to GW	NA	0.3	0.3	NA	0.001	0.001

All runs screen out

Key to abbreviations: CT = central tendency; HE = high end; GW = groundwater; SI =surface impoundment; WMU = Waste Management Unit

Table 3-10. Summary of Groundwater Results for 1,1,2-Trichloroethane: Ratios of Calculated Risk to Target Risk

Risk = 1E-5, Aerated Treatment Train

WMU	Pathway	Ingestion			Inhalation		
		CT	Min HE	Max HE	Ct	Min HE	Max HE
Secondary Clarifier	alternate uses	0.07	0.2	2 D7	0.1	0.3	3 D7
Landfill (primary clarifier sludge)	leachate to GW	0.1	0.4	23 D7	0.2	0.7	35 D7
Landfill (secondary clarifier sludge)	leachate to GW	0.007	0.02	1.2 D7	0.01	0.03	2 D7

Risk = 1E-5, Nonaerated Units

WMU	Pathway	Ingestion			Inhalation		
		CT	Min HE	Max HE	Ct	Min HE	Max HE
Surface Impoundment	leachate to GW	0.03	0.1	8 B4	0.05	0.2	12 B4
Landfill (SI sludge)	leachate to GW	0.003	0.01	4 B4	0.005	0.02	7 B4
Landfill (tank sludge)	leachate to GW	NA	0.02	7 B3	NA	0.03	11 B3

Shaded values to not screen out
The code following values that do not screen out indicates the scenario that resulted in the displayed result
The letter refers to the overall scenario, and the number to the specific source scenario within the lettered scenarios
Key to abbreviations: CT = central tendency; HE = high end; GW = groundwater; SI = surface impoundment; NA = not applicable; WMU = waste management unit

3.3 Discussion of Uncertainties/Limitations for the Groundwater Pathway

This section identifies the major sources of uncertainty and qualitatively describes how each may influence the results of the risk assessment.

- *Wastewater storage, disposal, and treatment.* The source modeling used an inlet concentration equal to the proposed headworks exemption level (1 ppm for the carcinogens benzene and 1,1,2-trichloroethane and 25 ppm for the non-carcinogen 2-ethoxyethanol). To the extent that facilities have industrial wastes other than spent solvents with lower concentrations of the chemicals of concern flowing through the same headworks, dilution of the solvents in waste code F002/F005 wastes may occur, which would result in a lower overall concentration of the target chemicals in the headworks and in lower risks.

- *Sludge management.* EPA did not explicitly model the landfill managing the sludge, or any partitioning that might occur there. The analysis assumes that the sludge has reached equilibrium partitioning between the solid and liquid phase in the wastewater treatment unit and that the liquid-phase concentration in the landfill will be equal to the liquid-phase concentration in the wastewater unit. This is a reasonable assumption because the chemicals modeled do not tend to partition heavily to solids; however, this assumption may slightly overestimate risk.

- *Groundwater fate and exposure modeling.* The IWEM model used to estimate fate and transport in groundwater and exposure to groundwater is environmentally conservative with respect to the location of receptors and the exposure factors. This may lead to an overestimate of the risks.

- *Groundwater fate and exposure modeling for 1, 1, 2-Trichloroethane.* The chemical 1,1,2-TCA undergoes transformation to 1,1-dichlorethylene (1,1-DCE) due to hydrolysis while being transported in the subsurface environments. The transformation product (1,1-DCE) is more toxic than the parent compound (1,1,2-TCA) by approximately an order of magnitude. The transformation product has similar fate and transport characteristics as the parent and, therefore, will likely result in lower protective levels compared with 1,1,2-TCA.. As the modeling results are based on the parent compound only, risk from 1,1,2-TCA will be even greater than shown in this report.

- Phase II risk modeling used actual F002/F005 spent solvent waste quantity data (tons-per-year from the EPA RCRA hazardous waste “Biennial Reporting System” (BRS) large quantity generator database), as a range of headworks influent values assigned to the model’s simulated wastewater treatment train. The Phase II modeling also assigned numerical ranges to other modeling input values based on actual geographic location characteristics (e.g. soil types and annual rainfall amounts) associated with the set of industrial facilities identified in the BRS database as generating this class of waste. However, for some of the facilities in this BRS data set, EPA does not know with certainty whether a facility may generate one or more of the four spent solvent chemicals of this study. The consequence of this source of uncertainty is that the risk modeling probably over-estimated the actual quantity of spent solvents which may be loaded into industrial wastewaters under the hypothetical exemption scenario for these candidate chemicals, and thereby over-estimated potential risks. (Note: EPA used the 1997 BRS data because that was the most recent data year available for public access to query at http://www.epa.gov/enviro/html/brs/brs_query.html.)

- EPA based the Phase II risk modeling on annual waste quantities and a set of facilities which are known to generate "aqueous" physical forms of F002/F005 spent solvent wastes, which are destined for management in wastewater treatment systems (See Data Background Documents for Headworks Exemption Rule Proposal; EPA, 2002). EPA believes that these two combined conditions provide a reasonable indicator to identify facilities (and associated waste quantities) which may claim the headworks exemption for one or more of these four candidate spent solvent chemicals. EPA is aware that some industrial facilities generate liquid but non-aqueous forms of F002/F005 spent solvents, but these waste quantities and set of facility locations were not included in the Phase II modeling, because EPA expects that concentrated liquid forms of spent solvents will be managed in recycling or energy recovery systems which enhances economic value to waste management, compared with alternative management in wastewater treatment systems. Furthermore, the generation of non-aqueous liquid forms of F002/F005 spent solvents represent a relatively small (3%) annual quantity, compared with the annual quantity of aqueous forms of F002/F005 spent solvents generated, which is well within other overriding precision intervals in other quantitative factors included in the Phase II modeling effort.

4.0 Indirect Pathway Screening Analysis

In Phase I, EPA assessed only direct exposures to a spent solvent chemical from wastewater treatment. It is possible, however, that environmental contaminants could be transferred to other media, resulting in an indirect exposure to the pollutant. In Phase II, EPA assessed both direct and indirect exposures resulting from sludge management.

An indirect pathway of exposure is a pathway through which a chemical that is released into one medium (for example, air) is subsequently transported to other media, such as water, soil, or food, to which a receptor is exposed. For example, chemical vapors that are released from a waste management unit and transported to an adjacent agricultural field may diffuse into vegetation, deposit on vegetation, or may be taken up by vegetation from the soil. Individuals who subsequently eat the produce from that field may be exposed to contaminants in their diet. Additional indirect exposures can occur through the ingestion of contaminated fish or animal products, such as milk, beef, pork, poultry, and eggs.

Figure 4-1 shows these pathways graphically. The arrows indicate the flow of pollutants through the pathways. Pollutants are released from a source, dispersed through the air, and deposited on crops, pastures, soil, and surface water. From there, they may be taken up into plants or animal tissues. Humans may then be exposed by ingesting soil (through hand-to-mouth contact), ingesting plant products, or ingesting animal products (including fish). For this screening analysis, the medium used to grow plants was assumed to consist of 100 percent sludge (at the concentration predicted by WATER9 in Phase II). Although not shown in Figure 4-1, humans may also ingest groundwater and surface water as drinking water sources. However, groundwater exposures are presumed to be less than those estimated in Phase II and discussed in Section 3. Surface water sources of drinking water are presumed to be treated to remove contaminants.

This section describes the indirect exposure methodology used to assess the proposed headworks exemption, the results of that assessment, and the uncertainties associated with it.

4.1 Methodology for Indirect Pathways

The chemicals under consideration for the proposed headworks exemption are not chemicals that EPA would expect to bioaccumulate significantly or pose indirect risks in excess of direct pathway risks. Therefore, EPA did a simple bounding analysis using conservative assumptions to determine if a more detailed indirect assessment was needed.

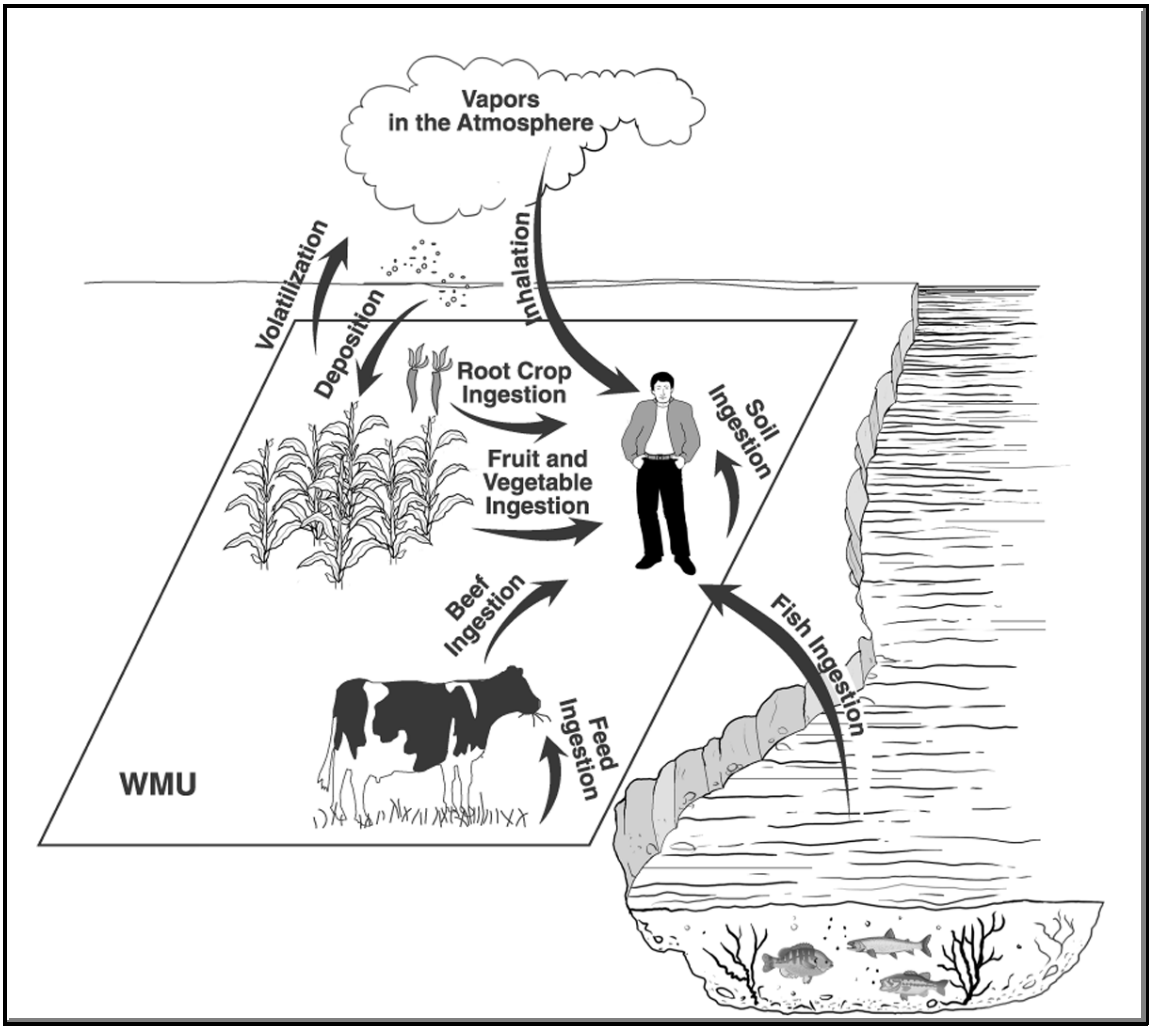

Figure 4-1. Indirect exposure pathways.

4.1.1 Scenarios

EPA conducted the indirect assessment for the same units as the Phase II groundwater assessment (nonaerated units and an aerated biological wastewater treatment train, as shown in Figures 1-1
and 1-2). The figures show, in bold, the pathways assessed for the groundwater and indirect analyses. For the indirect analysis, the following pathways were considered:

- Indirect pathways from land application of sludge from a nonaerated storage tank,
- Indirect pathways from land application of sludge from a surface impoundment,
- Indirect pathways from land application of sludge from a primary clarifier, and
- Indirect pathways from land application of sludge from a secondary clarifier.

The activated sludge unit is assumed not to generate sludge, because it is aerated to prevent solids from settling.

In keeping with the bounding nature of the indirect analysis, EPA evaluated these pathways using only two scenarios—one with central-tendency inputs for the wastewater treatment source modeling and one with high-end inputs for the source modeling. These scenarios are intended to characterize the extreme high end of the range of indirect risks. As with groundwater, to define "high end," EPA first considered the components of the risk paradigm: source characterization, fate and transport, exposure, and toxicity. Each of these components encompasses one or more input variables.

The indirect analysis used the same source scenarios as the Phase II groundwater assessment (see Tables 3-5 and 3-6). Those scenarios encompass both central-tendency and high-end scenarios with respect to source. Fate and exposure are set to high end by virtue of the scenario modeled and the specific modeling assumptions used rather than by setting specific input parameters to high-end values. The modeling assumptions are discussed further in Section 4.1.2. Toxicity is represented by the health benchmark for either oral or inhalation exposure. Toxicity is not typically varied—EPA has established a single value for most health benchmarks used in risk assessment. However, the toxicity data for benzene support a range of values for the oral and inhalation cancer slope factors. For the indirect assessment, the high end of the range for benzene was used.

Table 4-1 summarizes the two main scenarios modeled. For this bounding analysis, EPA assumed that the sludge generated by the wastewater treatment units was applied to an agricultural field on which a farmer raises beef cattle and crops for personal consumption. Runoff occurs to an adjacent stream, where the farmer catches fish for personal consumption. EPA considered exposures to both an adult and child farmer.

Table 4-1. Summary of Scenarios Modeled for Indirect Bounding Analysis

	Scenario	
Component	**H**	**I**
Source	central	high
Fate	high	high
Exposure	high	high
Toxicity	high	high

4.1.2 Modeling Approach

The source modeling was identical to the source modeling done for the groundwater analysis described in Section 3. This section describes the indirect modeling portion of the approach.

The indirect modeling scenario is an agricultural field on which a farmer raises beef cattle and crops for personal consumption. Runoff occurs to an adjacent stream, where the farmer catches fish for personal consumption. The analysis considers the following specific pathways:

- Ingestion of soil,
- Ingestion of beef,
- Ingestion of above- and belowground vegetables,
- Ingestion of fish, and
- Inhalation of ambient air.

Ingestion of milk was not considered because the octanol-water partition coefficient for all three of the chemicals considered—benzene, 2-ethoxyethanol, and 1,1,2-trichloroethane—was below the low end of the applicable range for developing milk biotransfer factors. As a result, milk ingestion is not expected to be an important exposure pathway for these chemicals.

Because the indirect assessment is a bounding assessment, very little fate and transport modeling was done. Instead, EPA made conservative assumptions. These assumptions include the following:

- Application and tilling of the sludge onto the field was not modeled. Instead, EPA assumed that the concentration in the sludge/soil mixture in the field was equal to the sludge concentration output by WATER9. Modeling the application and tilling would reduce the effective sludge/soil concentration below that of the sludge itself.

- Contaminants were not repartitioned within the field. The solid and liquid concentrations output by WATER9 for the sludge were directly used to represent the field concentrations.

- No transport modeling was performed for the runoff-to-stream pathway. The surface water concentration was assumed to equal the liquid concentration output by WATER9. In fact, runoff from the field would be diluted within the waterbody, and a realistic concentration would be lower.

- No transport modeling was performed for any of the farm foodchain pathways—the farmer was assumed to be farming on the sludge. Thus, no overland transport of contaminants from the applied sludge area to adjacent agricultural fields was modeled.

The remaining fate and transport modeling was done using simple models. Volatilization of contaminants from the sludge was modeled using a simple volatilization factor approach that was used to develop the Superfund Soil Screening Levels (U.S. EPA, 2001c). Wet and dry deposition rates onto soil and plants were assumed. Entrainment of particles to air was not considered. These chemicals are all sufficiently volatile that the fraction of air concentration that is vapors is expected to be 1.

Plant uptake from vapor-phase deposition and via the roots from soil was modeled using standard biotransfer factors. Beef cattle were assumed to graze, consuming soil and plants. Uptake to edible tissues was modeled using standard biotransfer factors.

Exposure factors were set to central-tendency values because the exposure scenario (a farmer growing crops and animal products directly on contaminated sludge) was conservative.

Appendices D through H document the equations, input values, and the sources for the values used in the indirect assessment in detail.

4.2 Results for Indirect Pathways

Tables 4-2 through 4-4 present the range of risks or HQs obtained for the ingestion and inhalation pathways. Ingestion values are summed across all ingestion pathways (i.e., soil, beef, vegetable, and fish). All ingestion values are driven by aboveground vegetable ingestion. The ranges represent the range across the different source modeling scenarios. Shaded values exceed a risk of 1E-5 or an HQ of 1.

Table 4-2. Summary of Indirect Results for Benzene: Risk

Aerated Treatment Train

WMU	Pathway	Ingestion		Inhalation	
		Min HE	Max HE	Min HE	Max HE
LAU (primary clarifier sludge)	leachate to GW	4E-06	9E-06	8E-08	3E-07
LAU (secondary clarifier sludge)	leachate to GW	1E-07	2E-07	2E-09	1E-08

Nonaerated Units

WMU	Pathway	Ingestion		Inhalation	
		Min HE	Max HE	Min HE	Max HE
LAU (SI sludge)	leachate to GW	3E-07	1E-05	2E-08	6E-07
LAU (tank sludge)	leachate to GW	1E-06	2E-05	1E-07	1E-06

Shaded values exceed 1E-5 risk
Driving pathway for ingestion is vegetable ingestion
Source is high end for Max HE column and central tendency for Min HE column
Fate is high end for all runs because no partitioning or transport was modeled
Exposure is high end for all runs—exposure duration is central (9 years) but receptor modeled is farmer, which has the highest risk of all receptors. Both an adult and a child were modeled
Toxicity is high end for all runs

Key to abbreviations:
WMU = waste management unit
LAU = land application unit
HE = high end
GW = groundwater
SI = surface impoundment

As expected, the risks are greater for sludges that come from nonaerated units and from units before the aerated activated sludge unit in the aerated treatment train than from aerated units and units after the aerated activated sludge unit in the aerated treatment train. None of the scenarios result in risks of concern for 2-ethoxyethanol. For benzene and 1,1,2-trichloroethane, none of the inhalation results exceed 1E-6. For ingestion, most scenarios result in risks at or below 1E-5. The highest risk result is 2E-5 (for nonaerated tank sludge via ingestion). Given the bounding nature of the indirect analysis, EPA believes these risk levels are not cause for concern and, therefore, more detailed analysis was not performed.

Table 4-3. Summary of Indirect Results for 2-Ethoxyethanol: HQ

Aerated Treatment Train

WMU	Pathway	Ingestion		Inhalation	
		Min HE	Max HE	Min HE	Max HE
LAU (primary clarifier sludge)	leachate to GW	0.3	0.3	0.0002	0.0002
LAU (secondary clarifier sludge)	leachate to GW	0.01	0.03	0.00001	0.00002

Nonaerated Units

WMU	Pathway	Ingestion		Inhalation	
		Min HE	Max HE	Min HE	Max HE
LAU (SI sludge)	leachate to GW	0.02	0.4	0.00002	0.0003
LAU (tank sludge)	leachate to GW	0.3	0.5	0.0003	0.0003

All HW values are less than 1
Driving pathway for ingestion is vegetable ingestion
Source is high end for Max HE column and central tendency for Min HE column
Fate is high end for all runs because no partitioning or transport was modeled
Exposure is high end for all runs—receptor modeled is farmer, which has the highest risk of all receptors. Both an adult and a child were modeled

Key to abbreviations:
WMU = waste management unit
LAU = land application unit
HE = high end
GW = groundwater
SI = surface impoundment

Table 4-4. Summary of Indirect Results for 1,1,2-Trichloroethane: Risk

Aerated Treatment Train

WMU	Pathway	Ingestion		Inhalation	
		Min HE	Max HE	Min HE	Max HE
LAU (primary clarifier sludge)	leachate to GW	4E-06	8E-06	6E-08	2E-07
LAU (secondary clarifier sludge)	leachate to GW	2E-07	5E-07	3E-09	1E-08

Nonaerated Units

WMU	Pathway	Ingestion		Inhalation	
		Min HE	Max HE	Min HE	Max HE
LAU (SI sludge)	leachate to GW	4E-07	1E-05	2E-08	5E-07
LAU (tank sludge)	leachate to GW	1E-06	2E-05	7E-08	7E-07

Shaded values exceed 1E-5 risk
Driving pathway for ingestion is vegetable ingestion
Source is high end for Max HE column and central tendency for Min HE column
Fate is high end for all runs because no partitioning or transport was modeled
Exposure is high end for all runs—exposure duration is central (9 years) but receptor modeled is farmer, which has the highest risk of all receptors. Both an adult and a child were modeled

Key to abbreviations:
WMU = waste management unit
GW = groundwater
LAU = land application unit
SI = surface impoundment
HE = high end

4.3 Discussion of Uncertainties/Limitations for Indirect Pathways

This section identifies the major sources of uncertainty and qualitatively describes how each may influence the results of the risk assessment.

- *Wastewater storage, disposal, and treatment*. The source modeling used an inlet concentration equal to the proposed headworks exemption level (1 ppm for the carcinogens benzene and 1,1,2-trichloroethane and 25 ppm for the non-carcinogen 2-ethoxyethanol). To the extent that facilities have industrial wastes other than spent solvents with lower concentrations of the chemicals of concern flowing through the same headworks, dilution of the solvents in waste code F002/F005 wastes may occur, which would result in a lower overall concentrations of the target chemicals in the headworks and in lower risks.

- *Sludge management*. EPA did not explicitly model the land application of sludge, tilling of sludge into the soil, or any partitioning that might occur there. The analysis assumes that the sludge has reached equilibrium partitioning between the solid and liquid phase in the wastewater treatment unit and that the solid- and liquid-phase concentrations in the modeled field will be equal to the solid- and liquid-phase concentrations in the wastewater unit.

- *Fate and exposure modeling*. The indirect assessment did not model fate and transport processes, but made environmentally conservative assumptions. Crops are assumed to be grown on the sludge, no dilution in surface water is assumed, etc. This assumption would certainly lead to a significant overestimate of the risks.

- *Ecological receptors*. Ecological receptors were not modeled because available ecological toxicity data were too limited to support a meaningful screening. Therefore, ecological risks were not considered. The actual risks to ecological receptors are unknown.

5.0 References

U.S. EPA (Environmental Protection Agency). 1994. Air Emission Models for Waste and Wastewater. Office of Air Quality Planning and Standards, Research Triangle Park, N.C. 27711. EPA-453/R-94-080A. Available online at: http://www.epa.gov/ttn/chief/software/water/.

U.S. EPA (Environmental Protection Agency). 1996. EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP), Background Document, Office of Solid Waste, Washington, D.C. 20460.

U.S. EPA (Environmental Protection Agency). 1996. Superfund Chemical Data Matrix (SCDM). Office of Emergency and Remedial Response. Web site at http://www.epa.gov/oerrpage/superfund/resources/scdm/index.htm. June.

U.S. EPA (Environmental Protection Agency). 1997. Exposure Factors Handbook. Office of Research and Development, Washington, D.C. 20460. EPA Report Number EPA/600/P-95/002Fa. August. http://www.epa.gov/ncea/exposfac.htm.

U.S. EPA (Environmental Protection Agency). 1999. Revised Risk Assessment for the Air Characteristic Study. Volume I: Overview; Volume II: Technical Background Document; Volume III: Results. Office of Solid Waste, Washington DC. EPA Report Number EPA530-R-99-019a, b, and c. August. http://www.epa.gov/epaoswer/hazwaste/id/air-risk.htm.

U.S. EPA (Environmental Protection Agency). 2001a. Industrial Surface Impoundments in the United States. Office of Solid Waste, Washington DC. EPA530-R-01-005. March. http://www.epa.gov/epaoswer/hazwaste/ldr/icr/impdfs/sisreprt.pdf.

U.S. EPA (Environmental Protection Agency). 2001b. Integrated Risk Information System (IRIS). National Center for Environmental Assessment, Office of Research and Development, Washington, DC. Available online at http://www.epa.gov/iris/.

U.S. EPA (Environmental Protection Agency). 2001c. Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites. Peer Review Draft. Office of Solid Waste, Washington DC. March. http://www.epa.gov/superfund/resources/soil/ssgmarch01.pdf.

U.S. EPA (Environmental Protection Agency). 2002. Industrial Waste Management Evaluation Model (IWEM) Technical Background Document. Office of Solid Waste, Washington, DC. EPA530-R-02-012.

U.S. EPA (Environmental Protection Agency). December 2002. Data Background Document: Supporting Information on the Four RCRA-Listed Hazardous Waste F002 & F005 Spent Solvent Chemicals. Office of Solid Waste, pp. 51 - 52. Washington, D.C. 20460, December.

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